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The study of the production of dimuons in the NA64 experiment

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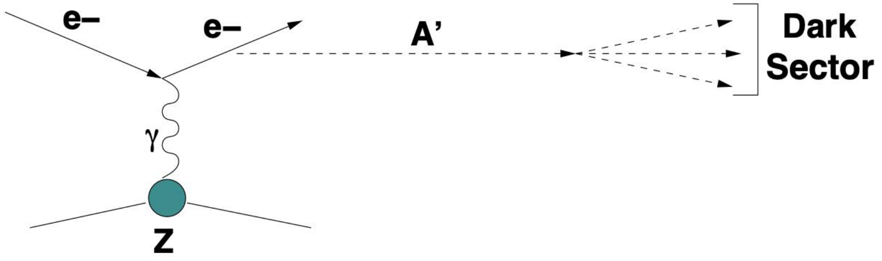
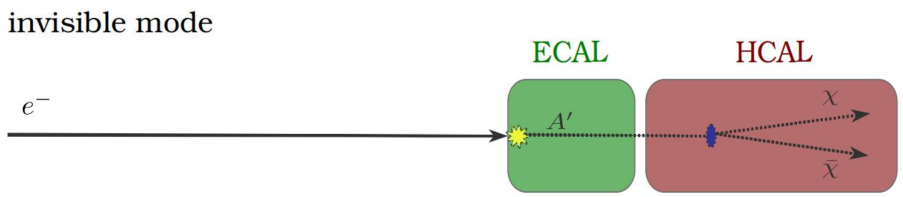
The NA64 experiment



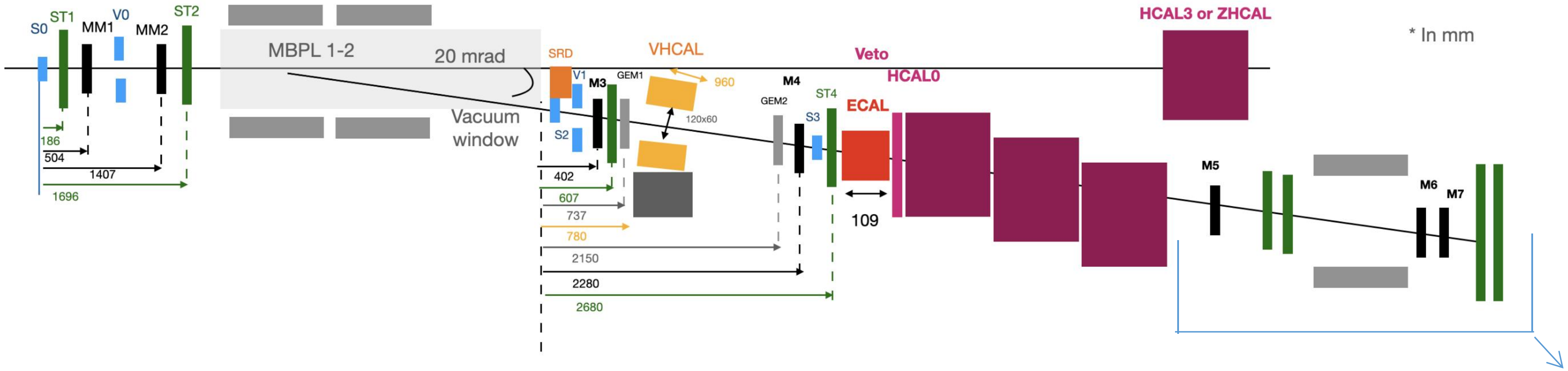
The A′ production in the reaction e–Z → e–ZA′, A′ → dark sector. (invisible decays into dark sector particles).

The NA64 experiment is a fixed-target experiment at the CERN SPS combining the active beam dump and missing energy techniques to search for rare events.

two decay channels: the visible and the invisible modes



The main goal ⟹ to search for sub-GeV dark matter production mediated by a new A’ vector boson, which is performed in energy-missing events from 100 GeV electron interactions in the active beam dump.



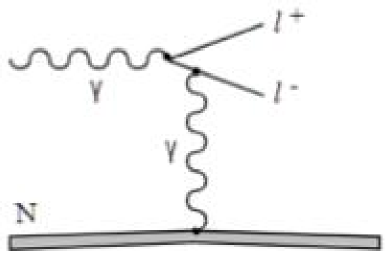
Sketch with the main detectors (top view)

the spectrometer has been installed since 2022

Motivation

Rare process $e^{-}Z \to e^{-}Z\gamma; \qquad \gamma \to \mu^{+}\mu^{-}.$

gamma conversion into pair muons (dimuons) inside an em-shower have a set of characteristics with signal events



Diagrams for lepton-pair production in the presence of nucleus N

dimuons are used to check the accuracy of the Monte-Carlo simulation of the NA64 setup based on the Geant4 package, also for calibrating the detectors, adjusting the selection criteria for candidate events A'. They also represent a BG source in the A' search

the production of dimuons inside the target.

TABLE I: Expected background for 2.84×10^{11} EOT.

Background source	Background, n_b
(i) dimuons	0.024 ± 0.007
(ii) π, $K \to e\nu$, K_{e3} decays	0.02 ± 0.01
(iii) e^- hadron interactions in the beam line	0.43 ± 0.16
(iv) e^- hadron interactions in the target	< 0.044
(v) Punch-through γ's, cracks, holes	< 0.01
Total n_b (conservatively)	0.53 ± 0.17

Motivation

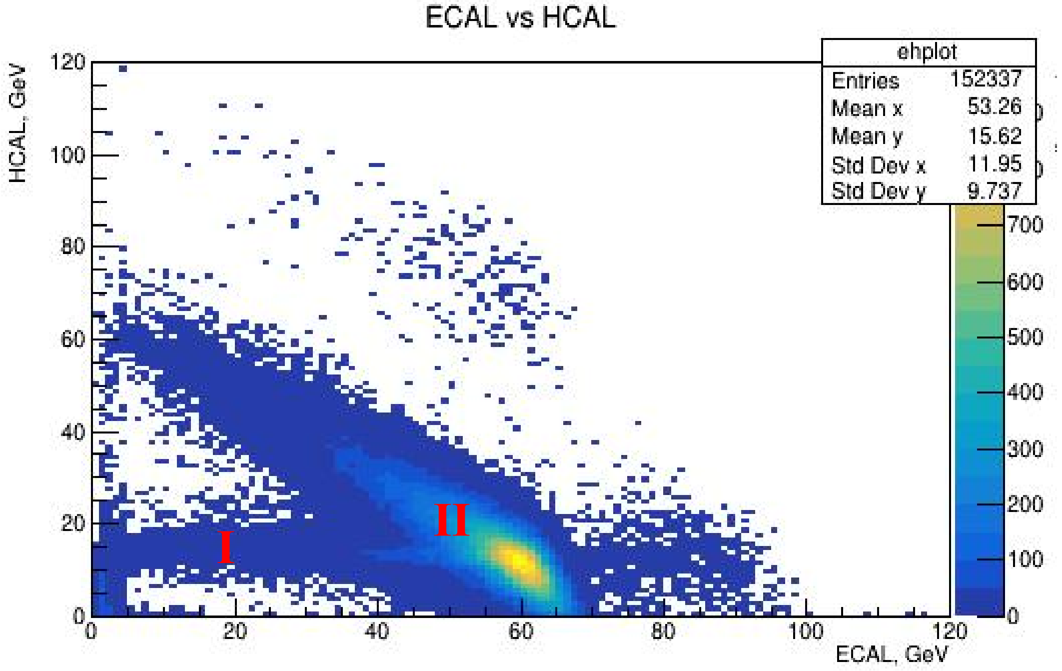
$$e^- Z \to e^- Z\gamma; \qquad \gamma \to \mu^+\mu^-.$$

The dimuons

- rare, produced inside an em-shower
- penetrate efficiently the target and the HCAL
- the same region of the signal ($0 < E_{ECAL} < 90$GeV)
- can be computed inside the QED framework*

But this process can be easily distinguished from a signal event.

the earlier phase of the analysis



I - QED dimuon production

II - events from the SM hadron electro-production in the ECAL

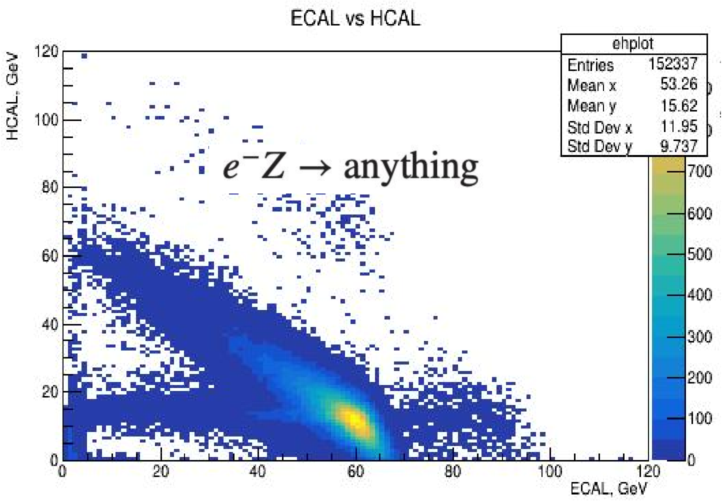
*In first approximation

Selection of events with the conversion in the invisible mode setup

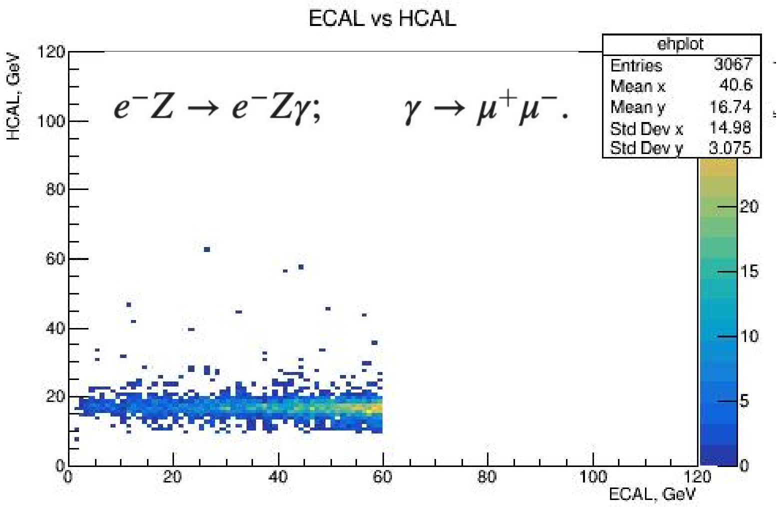
- using the synchrotron radiation detectors (SRD)
- energy deposition in the active target (ECAL). The trigger accepts only events with the calibrated energy deposition smaller than ~85 GeV in the 100 GeV electron beam. For studies closer to the signal region the selection cut is usually (< 60 GeV)
- using the energy deposition in the HCAL modules. because only muons can reach modules 1 - 3 of the HCAL.

1 $E_{ECAL} < 60 \text{ GeV}$

2 $1.2\,\text{GeV} < E^{1,2,3}_{HCAL} < 6.35\,\text{GeV}$



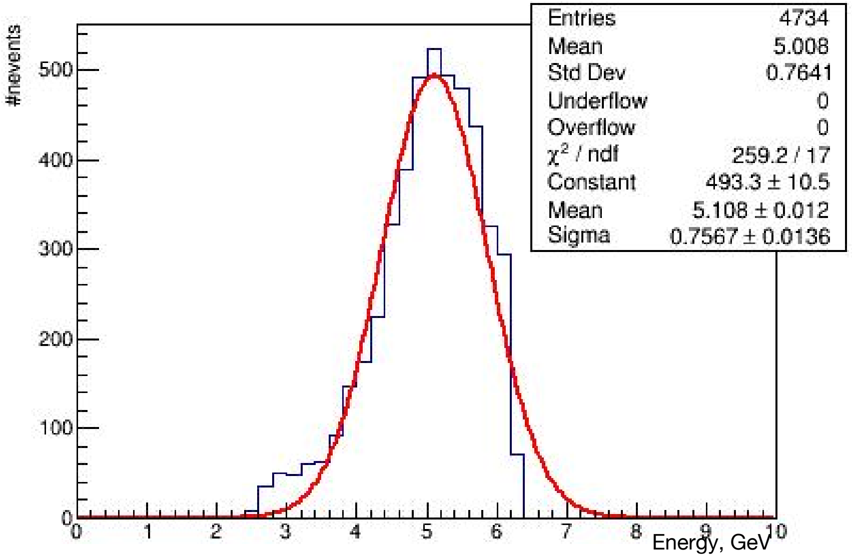
Energy distribution for electron run with SRD selection criteria



*Dimuon events in the 2D plot; fter selection criteria **1***

Data and modeling results

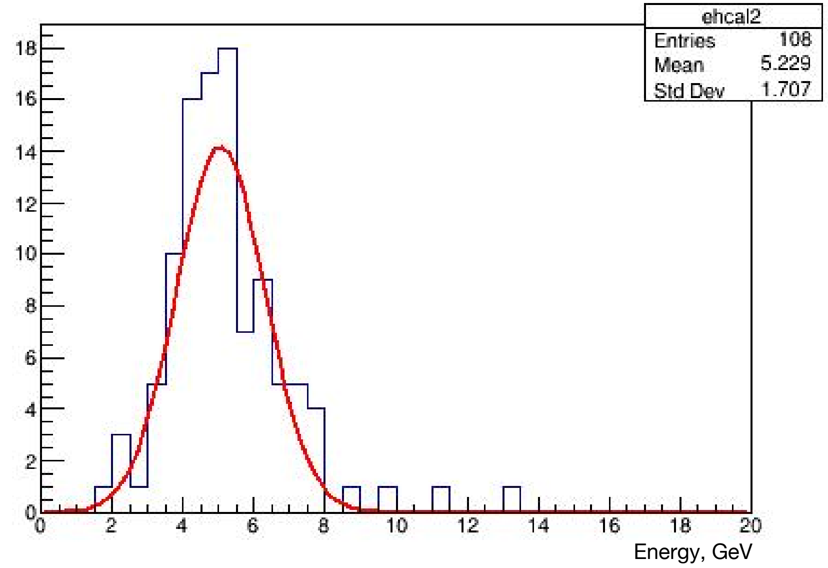
Data



The Dimuon peak in the HCAL module 2 for the run 8914 electron mode 2023

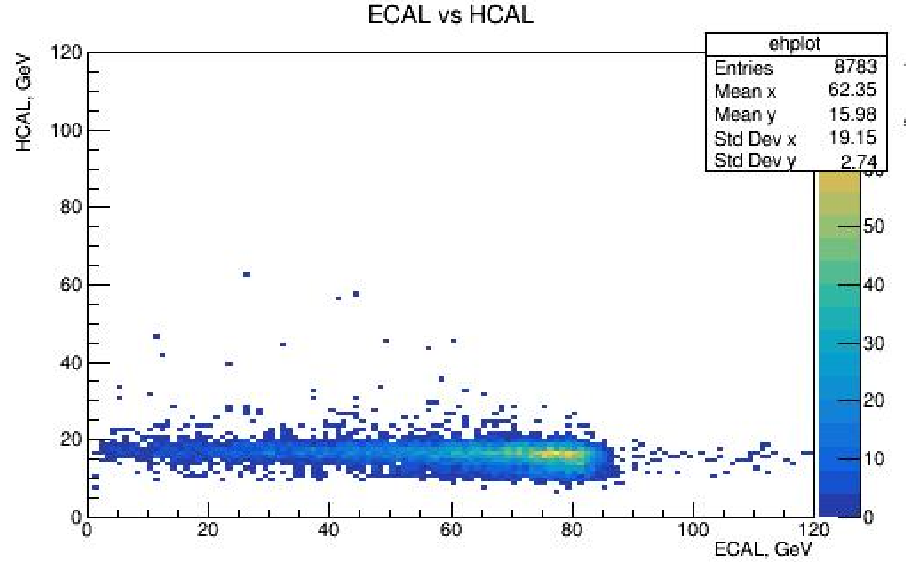
$9{,}03 \cdot 10^8$ Electron On Target

MC



The Dimuon peak in the HCAL module 2 from Monte-Carlo simulation on the NA64 setup

Estimation of the total number of dimuon events per one run on the NA64 setup



Summary

- The production of muon pairs is an interesting process, the study of which will give a number of advantages to the NA64 project
- The study of dimuons is interesting in itself, since it can provide information about the form factors of nuclei and check the implementation of this process in the Geant4 package.
- At the present analysis stage (essentially only calorimeters are used) the dimuons in data and MC are in good agreement

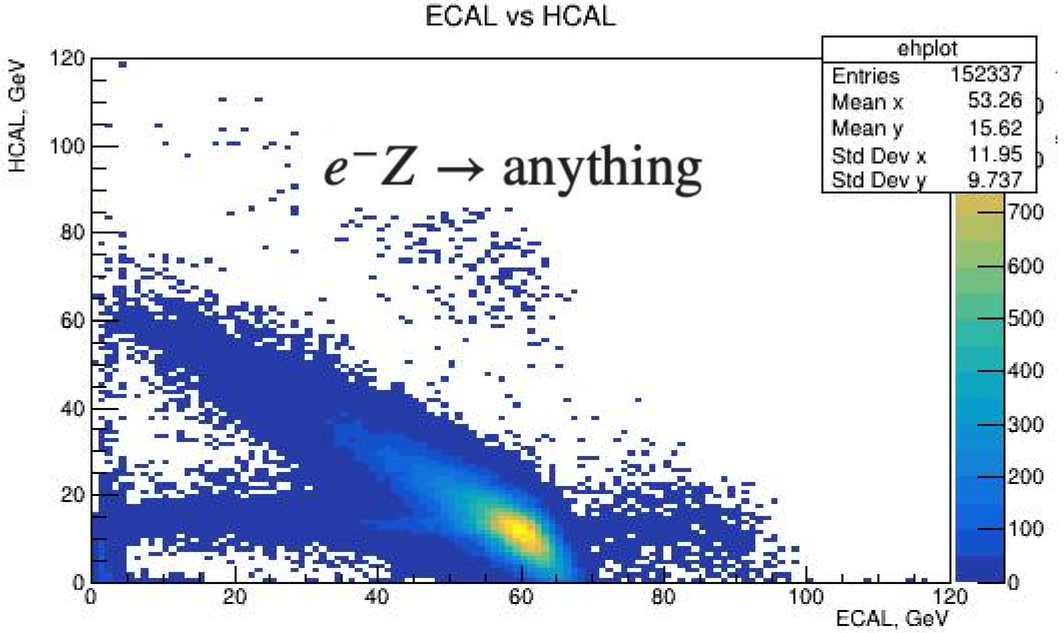
According to the analysis of runs, The NA64 has the largest sample of dimuon events in the range of 10 - 100 GeV.

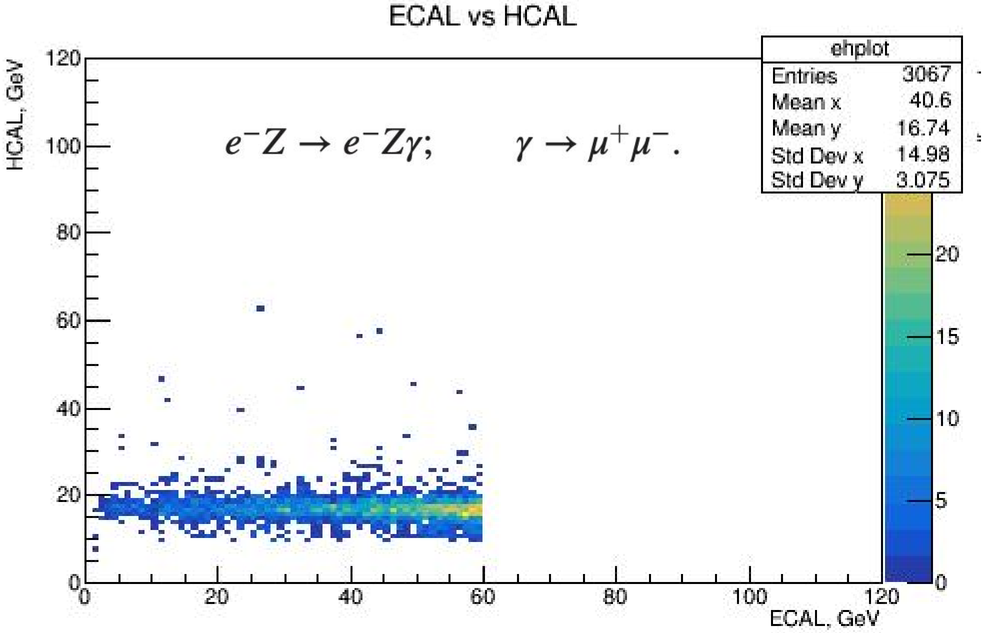
Thank you!

Back-up

Distribution of selected dimuon events for electron run 2022

The HCAL energy is defined as the total energy deposited in the four HCAL modules.





Dimuon events in the 2D plot.
Selected dimuons events in the (E_{ECAL}; E_{HCAL}) plane (electron run).
ECAL energy is required to be smaller than 60 GeV

Event distribution in the (E_{ECAL}; E_{HCAL}) plane for electron run 2022. The panel show the measured distribution of events at the earlier phase of the analysis (only SRD cut).

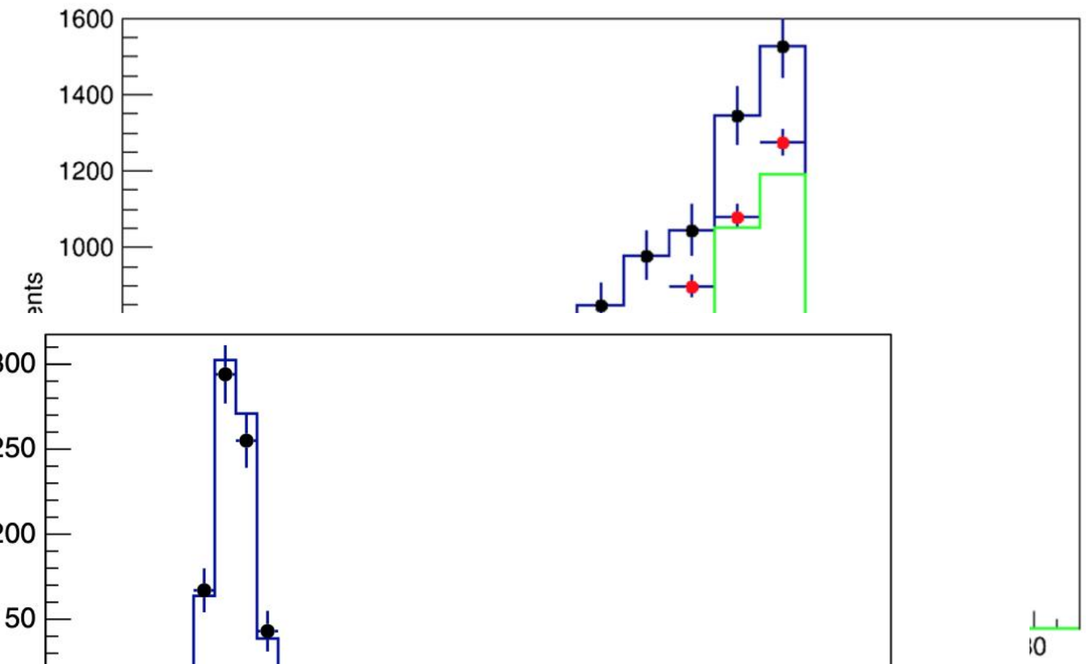
Simulation of the process $e^- Z \to e^- Z\gamma; \qquad \gamma \to \mu^+\mu^-.$

In Geant4, the process is described starting from the formula [155]:

$$\sigma_{tot}^{\gamma\to\mu^+\mu^-}(E_\gamma) = 4\alpha Z^2 r_c^2 \int_{x_{min}}^{x_{max}} \left(1 - \frac{4}{3}x_+x_-\right) \log W dx_+$$

Where x^+ is the fraction of energy of the original γ being transferred to the μ+ and W is a function of x^+,Eγ, and the Z, A of the element, which also takes into account both the atomic-screening using the Thomas-Fermi model and the finite size of the nucleus.

After the dimuon pair is generated, the amount of energy transferred to the μ+ is decided by sampling the differential cross section and the new particles are produced in Geant4. Since the interaction is approximately elastic, the relation $E\gamma = E\mu^+ + E\mu^-$ is used for the computation.



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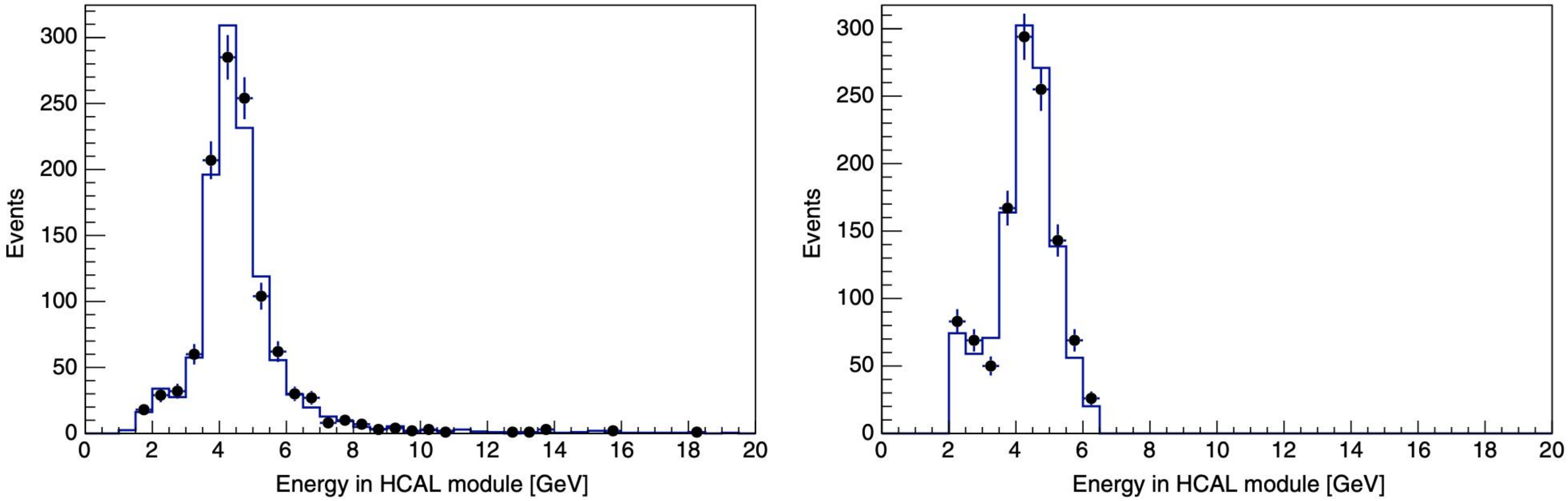

FIG. 9. Comparison of expected (solid) and measured (dots) distributions of dimuon events in the HCAL2 (left panel) and HCAL module 3 (right panel). The small bump at ≃2.5 GeV originates from a single muon of the pair when the other one stops in the previous module. The spectra are normalised to the same number of events.

spectra are in a reasonable agreement and are not signifi-
cantly distorted by pileup events.

The dimuon yield was estimated from the observed number of reconstructed dimuon events. The comparison of the number of observed ($n_{2\mu}^{\rm data}$) and predicted ($n_{2\mu}^{\rm MC}$) $\mu^+\mu^-$ pairs and the corresponding reconstruction efficiency ($\frac{n_{2\mu}^{\rm data}}{n_{2\mu}^{\rm MC}}$) is shown in Table I. One can see, that the reconstruction efficiency of $\mu^+\mu^-$ pairs were found to be beam rate
een the number of observed
ts with $E_{\rm ECAL} \lesssim 60$ GeV is
interpreted as due to the
ld determination for heavy
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the signal efficiency, which
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uon and A' events which is
ighting procedure discussed

TABLE I. Dimuon selection efficiency for the data samples from the runs I–III obtained at different beam intensity for $E_{\rm ECAL} < 60$ GeV.

Data sample	beam intensity, 10^6	$n_{\rm EOT}$, 10^6	$n_{2\mu}^{\rm MC}$	$n_{2\mu}^{\rm data}$	Efficiency reduction factor f
run I	1.8	171	1223	1124	0.92
run II	3.2	208.5	1491	1268	0.85
run III	4.6	597	4271	3417	0.81